The theory of this body is, however, as yet so incomplete that the Paris Academy has announced a prize for a satisfactory theory. Such a theory also presupposes the determination of *Titan's* mass. On the other hand, a comparison of the theory with observations would give a determination of the mass. Thus, the mass of *Saturn* could be deduced with tolerable accuracy from the disturbances in *Jupiter's* orbit. In *Titan's* orbit similar deviations may be found, which, however, on account of the slight mass of *Hyperion*, must be less prominent than the disturbances of the latter. From these, nevertheless, the mass of even such a small body could be determined with some accuracy.

THE CIRCULATION OF THE ATMOSPHERE OF PLANETS.

By Marsden Manson, Ph. D.

Our knowledge of the circulation of the atmosphere of planets has been so befogged by detail, that the grand and simple principles involved are lost in the maze of irrelevant and incompetent data which has been woven about the subject.*

The problem is intricate when attacked solely from the standpoint of the meteorologist, and it is doubtful whether an explanation of the prime mode of action of solar energy in producing atmospheric circulation has place in any treatise or text upon the subject. It is certain that none of the laws and formulæ laid down in meteorology will explain the grandeur and the delicate balance of the movements observed in the atmosphere of *Jupiter*. Nor will these complicated and empirical rules explain the

* The writer was led into making this investigation in a very peculiar manner, and it may not be inappropriate to outline the facts.

The amounts and distribution of rainfall upon the Pacific Coast became a subject of interest to the writer in 1877. This limited study broadened into a general one of the state of meteorology. Repeated failures to grasp the scope of the fundamental facts and laws, through these sources of knowledge, led into the general question as to whether the interpretations of meteorology would, in their simplest form, explain the movements observed upon *Jupiter*.

The view was entertained that the fundamental laws of the circulation of the atmosphere were true for all planets.

An apology is also due for the crudeness of the form in which these studies are presented — for their preparation has been confined to the moments which can be snatched from bread-winning in other lines.

apparently complex and confusing movements of the Krakatoa dust cloud, which, in 1883, gave such splendid opportunities to observe atmospheric movements.

Even the distinguished committee appointed by the Royal Society to investigate the phenomena attendant upon the Krakatoa explosion were forced, under present views, to partly attribute the movements of that cloud to "other laws than those which regulate the motion of the air in which it floated." The truth of the matter is, that the dust cloud floated in exact accordance with the laws which regulate the movement of the atmospheres of planets; but the laws heretofore given are the empirical laws of man, and not the interpreted laws of nature.

It is therefore necessary to develop the prime mode of action of solar energy in producing atmospheric circulation upon the globe, and to apply the same reasoning and methods to elucidate the movements in the Jovian cloud system.

It is a known fact, established by many extended series of observations, that the barometer has, at all latitudes, a daily variation caused by the action of solar energy. This rise and fall is greatest in the torrid zone, gradually dying away to an almost imperceptible phase in the polar regions.*

This phenomenon assumes the form of a diurnal pulsation, with a maximum about 9 A. M., and a minimum about 3 P. M., with a tendency to a corresponding maximum and minimum at 9 P. M., and 3 A. M. These latter pulsations are much less pronounced, and in the higher latitudes are scarcely appreciable. The diagram, Fig. I, illustrates this very marked feature.

It will be observed: (1) That under these conditions the lune of daily minimum barometer is always in the easterly quadrant of the illuminated hemisphere, that the lunes farther east have just been exhausted, and that those to the west are at their maximum. (2) That this action takes place continuously at each revolution of the earth. (3) That cloudiness accelerates and intensifies the action by appropriating all of the solar energy reaching the clouded areas. (4) That it is not counteracted in any way whatever.

Therefore, there results a constant lune of lowest barometer always in the easterly quadrant of the illuminated hemisphere,

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* See *Physical Geography of the Sea*. MAURY. p. 210. 8th edition.
Elementary Meteorology. R. H. SCOTT, F. R. S. pp. 88–91.
DESCHANEL'S *Natural Philosophy*. 6th Edition. p. 165.

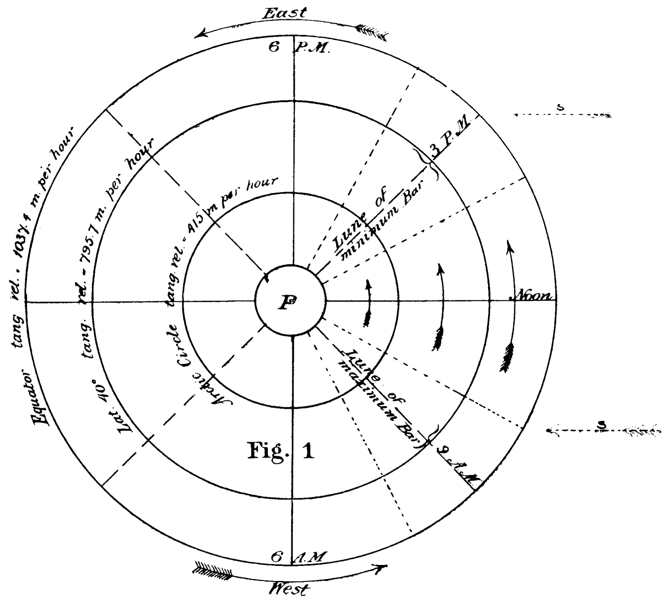


Fig. 1

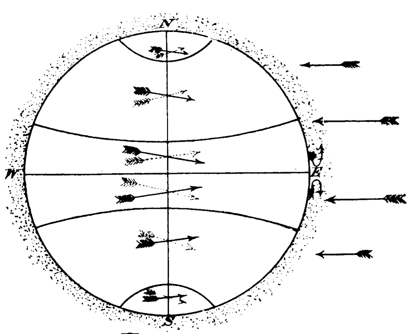
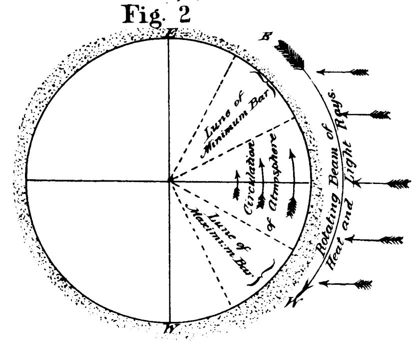


Fig. 2



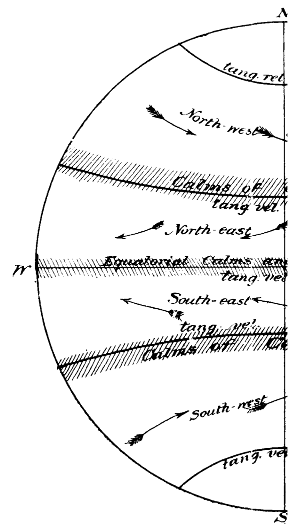
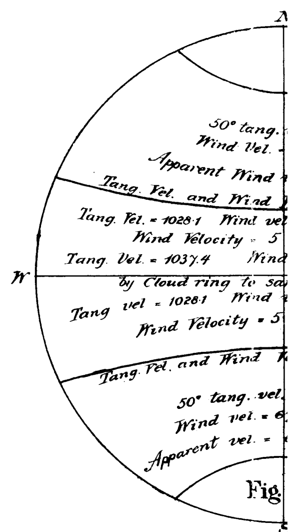


Fig.

Velocities expressed



Fig

Velocities expressed

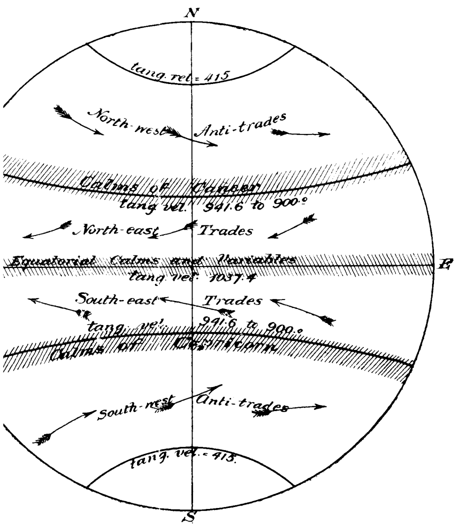


Fig. 3

Velocities expressed in miles per hour.

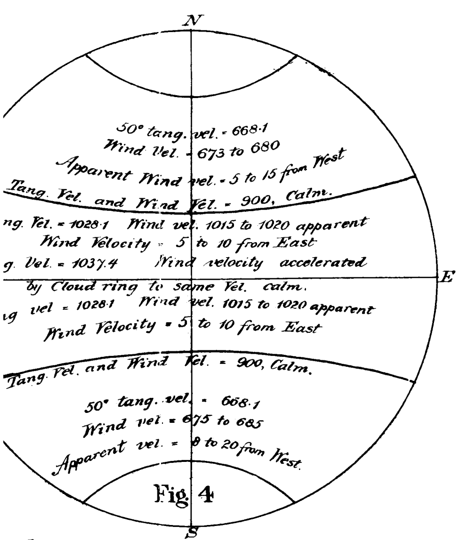
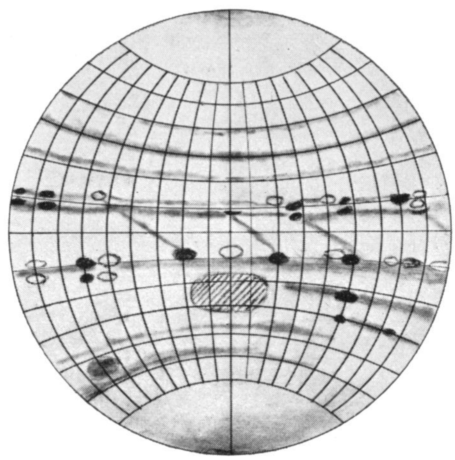


Fig. 4

Velocities expressed in miles per hour.

Fig. 5



THE PLANET JUPITER, 1887.

Modified from the Mercator's Projection in Zenographical Fragments.

which, by reason of the daily axial revolution, moves round the earth from east to west about ninety degrees (or six hours) east of the lune of maximum barometer; this condition can only be satisfied by a constant flow of air in the direction of this barometric gradient, or from west to east.

As solar energy has its greatest effect in the torrid zone, and gradually decreases toward the poles, westerly currents and vertical circulation reach their maximum in that zone, and the lower strata of air in each hemisphere have a slight trend toward the equator, and the upper strata a necessary counter current toward the polar regions.

It becomes necessary here to explain the apparent stoppage of the winds in the calms of *Cancer* and *Capricorn;* the apparent reversal of the west winds into the easterly trades of the torrid zones; and the existence of a calm belt between these two belts of easterly trades.

For illustrative purposes, let us assume a sphere in space, without axial rotation, and surrounded by an atmosphere similar in composition to that of the Earth. Around this sphere let us further assume a beam of heat and light to revolve from east to west, successively heating the air.

Barometric phenomena, similar to those now known to take place and illustrated in Fig. I, will be inaugurated; and if the revolutions of the beam of heat could be accomplished in twenty-four hours, and the heat received by each hemisphere be in whole or in part lost during the following period of non-exposure, the atmosphere surrounding our illustrative sphere would flow around it from west to east; and as the zone of nearly normal rays would be most acted upon, the west winds of that zone would be the strongest and the vertical circulation greatest. There would also be established a series of counter currents in the upper atmosphere trending toward the poles, and the resulting circulation would be as represented in Fig. II.

It will be observed: (1) That the strongest westerly winds and vertical circulation upon our non-rotating sphere will obtain under the zone of vertical rays, and that these winds will gradually decrease in force toward the polar regions, to die away at the poles. (2) That surface winds will trend toward the equatorial regions by reason of the greater vertical circulation there established, and an upper system of counter currents will trend toward the polar regions. These two wind systems will there-

fore be as represented by the full and dotted arrows in Fig. II, the varying lengths being intended to indicate the proportionate strength of the currents.

Now, instead of the assumed and impossible stationary sphere and revolving beam of heat, let us substitute the simple and actual stationary beam of heat and the rotation from west to east of the sphere. There will be no change in the forces tending to cause the atmosphere to circulate about the sphere, nor will conditions be introduced which would in any way tend to counteract such circulation, but remarkable relations between the atmospheric circulation and the moving surface will be introduced. All latitudes of the surface will travel with the atmosphere, but with varying relative velocities in each latitude.

In regions where the two velocities are equal, there would be apparent calms. In regions in which the tangential velocity exceeded the atmospheric velocity, there would be a differential motion — the planetary surface, moving to the east at a greater speed than the air, would pass the air, giving rise to an apparent east wind. The air would be going to the east with the lesser velocity. In regions in which the tangential velocity of the surface was less than the atmospheric velocity, there would be an actual west wind, the air in this case moving to the east with the greater speed.

The greater vertical circulation at the equator with its necessary oblique movement of air toward the equator at the surface and toward the poles in the upper atmosphere, need not now be taken into consideration, for as will be shown later, the ratio between longitudinal motion and latitudinal motion in the great body of the air is as 720 to 36, or 20 to 1; in the thin stratum next the surface these ratios do not obtain.

The question of whether the atmosphere would revolve with the planet, irrespective of the effect of solar energy, is not considered. The principal subject under discussion is the accelerating effect of solar energy. In temperate latitudes, where the rays pass obliquely through the atmosphere, this accelerating effect is so great as to cause the atmosphere to revolve faster than the Earth.

The tangential velocities are expressed in the table appended, which gives the velocity of the surface at sea level for each ten degrees of latitude. It is practically correct, but subject to very slight corrections, as the exact form and dimensions of the Earth shall be more minutely ascertained.

TANGENTIAL VELOCITY OF EACH TEN DEGREES OF LATITUDE FROM THE EQUATOR TO THE POLES.

Latitude.	Tangential Velocity in Miles Per Hour.	Remarks.	
0°	1037.4	Equator.	Calm.
10°	1021.8		
20°	975.3		Easterly Trades.
23½°	941.6	Tropics.	Calm.
30°	899.1		
40°	795.7		Westerly Anti-trades.
50°	668.1		
60°	520.0		
66½°	415.0	Polar Circles.	
70°	355.8		
80°	180.7		
90°	00.0	Poles.	

The appended diagram of the wind systems of the globe, Fig. III, is familiar and generally accepted. The variations are many, and produced by various causes, the principal of which are the different proportions of solar energy taken by ocean and continental areas; the varying exposure of winter and summer, and the transfer of heat by ocean currents, each of which locally complicates the actual phenomena, but all are foreign to a discussion of the prime problem, and will not now be considered.

It will at once be admitted that in the region of the anti-trades, or north and south of the calms of *Cancer* and *Capricorn*, the circulation agrees with that established and explained in Fig. II. In other words, between thirty-five degrees and sixty degrees in both hemispheres, the air circulates about the globe from west to east a few miles faster per hour than the tangential velocity in those latitudes. But about latitude thirty degrees, the acceleration in tangential velocity brings it up to the westerly circulation of the atmosphere, and both reach a velocity of about 900 miles per hour, and hence a region of calms. Between these two calm belts there is a zone in which the motion from west to east is actually greater than in the calm zones on each side, but owing to the proportionately greater increase in tangential velocity, these

stronger west winds appear to be east winds — the earth slipping under the air faster than the air circulates.

In the center of this great belt of easterly trades is a narrow belt of calms and variables — in which the velocity of the atmosphere and the tangential velocity are equal.

This narrow belt of calms is under the equatorial cloud-ring, and is exposed to vertical rays, and, by reason of its cloudiness, intercepts a larger portion of solar energy than the less clouded areas to the north and south of this ring. The effect of this intercepted heat is to accelerate the westerly currents of that region, thus equalizing the two velocities, and resulting in the equatorial calms.

The general relations of the tangential velocities to the actual atmospheric velocities are outlined in Fig. IV. The apparent atmospheric velocities or winds are the differences between the actual surface velocities and the actual atmospheric velocities.

It would be difficult to verify these views from the ordinary meteorological observations, particularly in the torrid zone; but an opportunity to observe the movements of the atmosphere on a grand scale was inaugurated on August 27th,* 1883, when in latitude six degrees nine minutes south, the volcanic island of Krakatoa, in the Straits of Sunda, was suddenly disrupted with a degree of violence unknown to history.

The Royal Society of London appointed a committee in December, 1883, to collect and put on record the observations made throughout the world upon the consequent phenomena. The results of the labors of this able committee were published in December, 1888, by G. J. SYMONS, F. R. S., chairman of the committee. From this valuable work the following outline is condensed:

The most violent explosions were heard at a distance of 2500 miles, and over one-thirteenth of the area of the globe, and threw a column of volcanic dust and vapor to a vertical height of from seventeen to thirty-one miles. The wave of atmospheric concussion traversed the globe to the antipodes of Krakatoa in sixteen hours, and, successively rebounding back and forth, compassed the globe seven times before subsiding. Every barometer marked seven successive passages of this rebounding wave, but its passage was rarely recorded except upon the baro-

* At this date the Sun was vertical over latitude thirteen degrees fifty-five minutes north.

graphs of the observatories. Masses of lava were thrown to a distance of fifty miles, with an initial velocity of 2500 to 3500 feet per second. The total volume displaced was about one and one-eighth cubic miles.

This vast dust column was borne by the winds twice and a half times around the Earth before being dissipated, making each circuit in about twelve and a half days, apparently in a westerly direction, and at an average rate of seventy to seventy-seven and two-tenths miles per hour. The probable maximum speed being estimated at eighty and three-tenths miles per hour, and by the celebrated Dutch engineer, VERBEEK, at eighty-two and nine-tenths miles per hour.

In the first circuit, the diffusion was over a zone of about thirty-one degrees in width; in the second, about sixty degrees in width; the center of each zone being practically the latitude of the explosion.

After passing latitude thirty-five degrees north, the further extension up to sixty degrees north was from the southwest.

From page 431 of the *Report* cited, the following quotation is introduced:

"If we analyze these, we shall find that on their first circuit, the mean latitude of the center of the band of the twilight glows, was six degrees ten minutes south (the latitude of Krakatoa being six degrees nine minutes south), and their mean extension north and south of this position was ± fifteen and one-half degrees.

For the colored suns, the mean latitude of the center of the band was five degrees twenty-six minutes south, and the mean extension of the phenomenon north and south of this was ± ten degrees and forty-nine minutes. The latter, therefore, was more restricted than, but very similar in position and extension to, the former.

During the second circuit, the limits are not so determinate; but, omitting extremes, we may take the twilight glow band to have had its central line about six degrees south, and to have extended north and south of this for about ± thirty degrees.

Up to October 5th, this rate of expansion for the stream seems to have been fairly maintained, but after this epoch we find a distinct retardation in the latitudinal spread of the main body of the haze, and thenceforward its course is doubtful. Apparently, it reached latitude thirty-five degrees by the end of October; then, in November, a sudden rush took place, which, by the end of the

same month, caused the phenomenon to be seen over the major part of North America and Europe, up to latitude sixty degrees. A change in the direction of motion appears to have taken place in October, after which the material seems to have been wafted along by a different set of currents.

Whether the material spread by the action of any other laws than those which usually regulate the motion of the air in which it floated, and at what time it ceased to move from east to west, it is difficult to say;*† but the facts negatively favor the view that by the time it reached latitude thirty degrees, it no longer possessed that due east to west direction, by which, at first, its general motion within the tropics was so markedly characterized. Beyond this limit, the facts relating to the march of the glows over North America, Europe, and Northern Asia, show that the current which brought the glow-causing material, whether simply the southwest anti-trade, or a current analogous to it at a higher level, carried it more from west to east than from east to west. There is, indeed, a remarkable absence of any succession of appearances from east to west beyond latitude thirty degrees north, *and a general impression conveyed by the facts that while the material was crossing this limit, it was simply spreading north and south, and afterward turned around so as to move, if anything, from southwest to northeast.*† If this was the case, its general motion beyond the tropics was similar to what that of the usually so-called higher parts of the atmosphere should be, according to the modern theory of atmospheric circulation."

It will be observed that in this quotation very important facts are recorded, but that a remarkable interpretation of them is rendered in referring to the apparent motion of the dust cloud, at from seventy to eighty-three miles per hour, from east to west, as an actual velocity in that direction — when in reality at this latitude this dust cloud was being borne in the opposite direction at much greater rate of speed.

The fact that this dust cloud traversed the Earth twice between latitude $\pm$ thirty degrees is beyond dispute. The observed time of passage was twelve and a half days, or three hundred hours. The distance accomplished in each circuit was the equatorial circumference of the Earth, at an altitude of twenty or

* Such as electrical repulsion.

† Italicized by the present writer.

thirty miles, or practically 25,000 miles. The tangential velocity of the equator is 1037.4 miles per hour from west to east.

By that well-known and useful principle established in the "Problem of the Couriers," the time necessary for one body to overtake another moving at a different rate, is found by dividing the distance between them by the difference of their rates of speed, or $T = \frac{D}{r - r_1}$ in which $T = 300$ hours; $D = 25,000$ miles; $r = 1037.4$ miles per hour, to find the velocity and direction of the dust cloud r_1.

Substituting these values, we find $r_1 = 954$ miles per hour. The sign being positive, the direction of motion is the same as the tangential velocity, and the difference between the two velocities is eighty-three and four-tenths miles per hour. In other words, the dust cloud, instead of being borne around the globe from east to west at an average speed of eighty-three and four-tenths miles per hour, was actually traveling in the opposite direction at a speed nearly eleven and one-half times greater, but the lost motion, or lagging behind the tangential velocity, was eighty-three and four-tenths miles per hour, giving an apparent motion from east to west. When the dust cloud reached the latitude of the tropics, or the calm belts, it traveled at the same velocity as the surface beneath, hence the "retardation" in October, 1883.

Upon passing north of the calms of *Cancer*, the haze reached the southwest upper currents, overspreading the northwest anti-trades, and moving faster than the surface beneath, and hence the apparent change in the direction of motion, and its spread over Northern Asia, Europe, and North America from the southwest. The change in direction spoken of in the quotation given was only an apparent change, due to the reversed relation between the tangential velocity of the surface and the velocity of the circulating air. The distinguished committee, in failing to correctly interpret the facts, found it necessary to partly attribute the motion of the dust cloud to "other laws than those which usually regulate the motion of the air in which it floated."

But when the principles herein developed are applied to the phenomena attending the movement and spreading of this volcanic dust cloud, these movements become grandly simple, and part of one harmonious whole.

We can also more readily interpret the two calm belts about

the tropics; starting in the torrid zone, or region of apparent east winds, where the tangential velocity is greater than the atmospheric velocity, and passing to the temperate zones, where the atmospheric velocity is the greater, we must pass through regions where the two rates of motion become equal, or the calm belts. Beyond these are the anti-trades, or the region of actual westerly winds, in which the velocity of the atmosphere is the greater.

In the regions of northwest and southwest trades, there is a proportionately greater acceleration, due to the greater appropriation by the atmosphere of the heat rays reaching those latitudes. By reason of the obliquity of solar rays, in latitude $\pm$ fifty degrees, nearly twice as thick a stratum of air must be passed through as at the equator; hence a larger proportionate amount of heat is taken up, and proportionately a greater acceleration is acquired by the atmosphere of those latitudes.

Thus the apparently confusing motions of the dust cloud in latitude thirty-five degrees north, and its apparent reversal of motion in approaching Europe and North America from the southwest, become part of a general circulation, always in the same direction, and in accordance with the same fundamental laws, acting in the same manner and in the same direction in all latitudes.

This velocity of 954 miles per hour is that obtaining in the higher regions of the atmosphere about the torrid zone. The relative surface velocities are more nearly as represented in Fig. IV. If the actual velocities of the atmosphere at various latitudes be compared with the scheme deduced from Fig. II, the correctness of this latter is at once established.

In the temperate zones, the actual surface velocities are about 675 to 680 miles per hour, gradually increasing to $\pm$ thirty degrees where velocities of about 900 miles per hour exist. In the tropical trade-wind belts the actual velocities are from 1010 to 1015 miles per hour; and under the equatorial cloud ring the actual velocity is about 1037 miles per hour. The differences between these velocities, and the tangential velocities of the corresponding latitudes give the apparent directions and forces of the winds.

The northerly and southerly components are omitted in this discussion, which is limited to the fundamental principles. The Krakatoa dust cloud encircled the globe twice before passing beyond the tropical calm belts, or, in going through 720 degrees

of longitude, it went from six degrees south to thirty degrees north latitude, or in the ratio of twenty to one. At the surface these components are relatively more nearly equal in value, and hence the directions of surface winds are more oblique to the meridians than the ratio above given would indicate.

PHENOMENA PRESENTED UPON *JUPITER*.

When the physical conditions and phenomena existent upon *Jupiter* are fully grasped, they present in their simplest and grandest form, the circulation of the atmosphere of a planet.

So far as our knowledge of *Jupiter* now extends, that planet is a mass of unknown size, shrouded in a densely clouded atmosphere. Not knowing the surface temperature of the inner planetary mass, nor the composition of the atmosphere, it is impossible to approximate the limit to which the gaseous envelope has been expanded. The cloud sphere evidently encloses a planetary mass, in which is still resident sufficient heat to control surface temperatures and to cause evaporation, thus maintaining the cloud sphere.

That evaporation is kept up on *Jupiter* by internal heat is made manifest by the following facts: Being 5.2 times more distant from the Sun than the Earth, he receives $\frac{1}{(5.2)^2} = .037$ of the heat per unit of area which the Earth receives. It is inconceivable that this amount of heat could keep up sufficient evaporation to shroud the planet in clouds. As will be shown later, this feeble amount of heat is entirely taken up in the atmosphere, and produces an atmospheric acceleration about the equatorial regions greater than the corresponding acceleration on the Earth. This decreased solar energy, by reason of producing a greater comparative acceleration, must therefore be taken up in the atmosphere to a greater extent than in the case of the Earth. The very existence, therefore, of the densely clouded atmosphere, is evidence of a surface temperature maintained by internal heat. It is also evident, as radiated solar energy is so largely taken up by the clouded atmosphere, and as we can detect no more heat in the rays emanating from *Jupiter* than is due to reflected solar rays, that the dark heat rays emanating from the planet itself cannot escape except in the performance of work. Therefore, the function of the solar energy reaching that planet is simply to conserve the internal heat. The cloud sphere of *Jupiter* having

a diameter eleven and two-tenths times larger than that of the Earth, and being five and two-tenths times more distant, intercepts $(11.2)^2 \times \frac{1}{(5.2)^2} = 4.64$ times more heat; every thermal unit of which has only this conservative function to perform.

The surface of this cloud sphere is marked by a series of bands and spots ranged in zones parallel with the equator. These spots are either dark or light, and exist for many months. Their periods of revolution are observed with great accuracy. After these bands and spots, the most notable feature is the Red Spot, situated in the southern hemisphere, and extending from about fifteen degrees south to thirty-two degrees south, and over thirty-five degrees of longitude, or one-eleventh of the circumference of the planet. See Fig. V.*

The Red Spot has a mean period of revolution of $9^h\ 55^m\ 38.4^s$, with a retardation of a few seconds per year for about six years, and then a similar acceleration. The most rapid revolution is $9^h\ 55^m\ 24.2^s$, and the slowest $9^h\ 55^m\ 41.1^s$. The spots in the bands have periods of revolution of from $9^h\ 55^m\ 46^s$ to $9^h\ 50^m\ 9.5^s$.

Those immediately adjacent to and north of the Red Spot have periods of revolution some five minutes less than that of the Red Spot, so that in about forty-five days they make one more revolution than it does, or they make 110 revolutions whilst the Red Spot makes 109. This swifter motion causes them to pass by the Red Spot, when it exercises a "repellant influence" upon them. Mr. WILLIAMS refers to the results of his observations as "demonstrating the great probability of the existence of a real repulsive influence exercised upon neighboring objects by this remarkable formation." But he offers no explanation of this phenomenon. The spots more remote from the Red Spot have nearly the same period of revolution. All of these periods of revolution are therefore variable. These variations are set forth in the accompanying tables from a recent and very able work, *Zenographical Fragments*, by A. STANLEY WILLIAMS, F.R.A.S.

The column of latitudes has been added by the writer from other parts of the same work. These latitudes mark approximately the center of each spot. There has also been added the

* In this figure, the zero of longitude is made the center of the Red Spot, the only prominent permanent feature. The spots are distorted to appear as they would when the planes of their meridians pass through the Earth.

column marked "Size," in which the letters "L" and "S" mark the large and small spots, the others being medium in size.

SUMMARY OF ROTATION PERIODS.

MEAN MOTION OF MATTER IN DIFFERENT ZENOGRAPHICAL LATITUDES IN 1887.

NORTH TEMPERATE SPOTS.	H.	M.	S.	Latitude.	Size.
White Spot A	9	55	34.7	12½° N	
Dark Spot B	9	55	40.4	10	L
Wh'te Spot C	9	55	32.6	12½	L
Dark Spot D	9	55	37.7	10	L
White Spot D^2	9	55	34.1	12½	L
Dark Spot E	9	55	27.3	10	S
White Spot F	9	55	30.0	12½	L
Dark Spot G	9	55	26.0	10	L
White Spot H	9	55	26.8	12½	.
Dark Spot H^2	9	55	40.7	10	S
White Spot K	9	55	38.6	11	L
Dark Spot K^2	9	55	39.4	10	S
White Spot L	9	55	38.5	13	.
Dark Spot M	9	55	43.1	11	L
White Spot N	9	55	46.0	12	S
Dark Spot O	9	55	44.0	10	
White Spot P	9	55	40.4	12½	

NORTH EQUATORIAL SPOTS.	H.	M.	S.	Latitude.	Size.
Dark Spot 1	9	50	16.6	8° N	
Dark Spot 2	9	50	33.3	8	
Dark Spot 3	9	51	18.7	5	L
Dark Spot 4	9	50	44.9	4	
Dark Spot 5	9	50	26.8	8	L

SOUTH EQUATORIAL SPOTS.	H.	M.	S.	Latitude.	Size.
Dark Spot I	9	50	22.3	10° S	
White Spot II	9	50	20.4	7½	
Dark Spot III	9	50	21.7	10	L
White Spot IV	9	50	17.4	7½	
Dark Spot V	9	50	9.5	8	L
White Spot VI	9	50	12.0	5	
Dark Spot VII	9	50	19.7	8	L
Dark Spot VIII		?		8	
White Spot IX	9	50	24.9	6	
Dark Spot X	9	50	19.2	6	
White Spot XI	9	50	15.5*	6	L
Dark Spot XII	9	50	19.0*	10	L

SOUTH EQUATORIAL SPOTS.	H.	M	S.	Latitude.	Size.
White Spot XV	9	50	21.9	7½	
Dark Spot XVI	9	50	24.0	10	
White Spot XVII	9	50	25.4	7½	L
Dark Spot XVIII	9	50	19.7	7½	L
White Spot XIX	9	50	18.0*	7½	L
Dark Spot XX	9	50	24.3	11	S
White Spot XXI	9	50	25.2	7½	
Dark Spot XXII	9	50	27.2	8	
White Spot XXIII	9	50	26.6	7½	S
Dark Spot XXIV	9	50	18.7	10	
White Spot XXV	9	50	29.7	7½	
Dark Spot XXVI	9	50	36.5	10	
White Spot XXVII.	9	50	24.1	7½	S

* Spots marked thus have been rejected in ascertaining the mean motion of matter in about latitude 8° S., their periods of rotation not being known with sufficient accuracy.

SOUTHERN SPOTS.	H.	M.	S.	Latitude.	Size.
Red Spot	9	55	40.5	24° S	L
White Spot α	9	55	21.6	30	
Dark Spot β	9	55	11.8	30	
Dark Spot γ	9	55	17.8	30	

	H.	M.	S.
Mean period of rotation of matter (from 17 north temperate spots) in Lat. 12° N.	9	55	36.49
Mean period of rotation of matter (from 5 north equatorial spots) in Lat. 4° N.	9	50	40.06
Mean period of rotation of matter (from 21 south equatorial spots) in Lat. 8° S.	9	50	22.4
Mean period of rotation of matter (from 3 southern spots) in Lat. 30° S.	9	55	17.1

(See page 111 of work cited.)

It will be observed that cloud spots in the equatorial regions have periods of revolution averaging some five minutes less than cloud spots in the less exposed temperate regions on either side; demonstrating that solar energy is the accelerating cause, and that the circulation of these spots is in accordance with the interpretation just rendered for the circulation of the atmosphere of the Earth.

It is probable that these spots are gyratory columns of warm air rising from and descending to the surface; the two forming essential components of the system of vertical circulation, and corresponding to the areas of high and low pressure, which alternately traverse the northern hemisphere at intervals of every few days.

It has been observed that during periods of great brilliancy and distinctness, the spots of the equatorial regions of *Jupiter* are subjected to a wave of acceleration passing westwardly in its action. The interpretation of this is, that in the upper strata, heat and light rays are at times partially arrested by cirrus clouds; during such partial interruption retardation takes place, and during non-interruption increased brilliancy and acceleration occur. The westward motion of the wave is due to the retardation by the cirrus cloud strata.

From the table just given it will be noted:

(1) That cloud spots in the south equatorial regions had, in 1887-8, a period of revolution faster than in any other portion of the visible surface.

(2) That in the north equatorial regions, nearly equal periods of revolution were maintained.

(3) That in the temperate latitudes, longer periods of revolution prevailed than in equatorial latitudes.

(4) That the Red Spot had a period of revolution distinctly slower than the adjacent cloud spots.

An Explanation of these Motions.

The Red Spot being the most permanent feature, an explanation of its oscillations and influence will first be offered.

It is evidently caused by the local escape of internal heat from the mass beneath, the *repellant influence* being due to the spreading of the heated currents as they rise, and to the consequent greater altitude and overshadowing effect of this remarkable feature.

The retardation and acceleration in its rate of revolution are due to the veering of the spot by the increasing force of west winds consequent upon the exposure of the southern hemisphere during one-half of the Jovian year, or five and ninety-three hundredths of our years. During the other half of the Jovian year these winds retreat northerly, permitting the Red Spot to assume a position in the atmosphere more nearly vertical over the

source of heat beneath, thus apparently retarding its motion to the east.

This acceleration and retardation of west winds, and the annual shifting of the belt of their maximum activity, are notably marked on the Earth.* It is very perceptible in its March and April passage over the central part of the continent of North America. It is also well known in the correlated shifting of the belts of trades and calms in the tropical latitudes of each hemisphere.

In spite of the slight variation in the rate of motion of the Red Spot, it affords the best measure of the Jovian day; and, taken for a long period, embracing both the summer acceleration and winter retardation, it gives the following measures:

Noting the mean period of rotation as fixed by 4,917 revolutions from July 10, 1879, to August 2, 1887, we have $9^h\ 55^m\ 38.4^s$ as the length of the Jovian day. This is four and two-tenths seconds longer than the shortest period observed in 1879-80, and two and seven-tenths seconds shorter than the longest period of revolution in 1885-86, about six years later.†

There also occurs in latitude forty degrees south, longitude fifty-five degrees to eighty degrees west, an indistinct spot of great size. So far as the author is aware, the exact time of revolution of this spot has not been observed. The opinion is ventured that it is caused by conditions similar to those producing the Red Spot, and that their periods are identical.

We have only to apply the principles herein developed to the varying periods of revolution of the belts of white and dark cloud spots in the atmosphere of *Jupiter*—and to bear in mind the non-diathermic character of his atmosphere—and these varying periods of revolution become simple, and in perfect accord with the explanations herein given for the wind systems of the globe. The wind system of *Jupiter* is more simple than ours, the acceleration in velocity being directly proportioned to solar exposure, and no heat is lost by passing through to a planetary surface having variable heat-appropriating powers.

The mean tangential velocity of the twenty-one spots observed in the south equatorial regions is 28,097.8 miles per hour.

The mean tangential velocity of the northern edge of the Red Spot (latitude twelve degrees thirty minutes south) upon

* See pages 578 to 663 of the *Report of the Chief Signal Officer, 1890.*

† See page 97, *Zenographical Fragments.*

the data just given is 27,149 miles per hour, the swifter motion of the freely-moving spots carrying them one more complete revolution in forty-five days than is made by the slower moving Red Spot. Those next to the line of juncture have a mean tangential velocity of 27,416 miles per hour, or they move 267 miles per hour faster than the northern edge of the Red Spot. In this forty-five-day period the south equatorial spots make 110 revolutions, and the Red Spot 109.

We have seen that in the equatorial regions of the Earth the Krakatoa dust cloud had a tangential velocity of 954 miles per hour, and that the surface of the Earth has a tangential velocity of 1037.4 miles per hour, or the partly transcalent atmosphere of the Earth does not keep up with the great equatorial tangential velocity; by reason of some of the heat passing through the air to the planetary surface beneath, the atmospheric tangential velocity lags, or is retarded by eighty-three and four-tenths miles per hour.

We therefore see that the lesser proportion of solar energy which reaches *Jupiter* produces an acceleration in tangential velocity above his enormous equatorial velocity, showing that his atmosphere takes up a much greater proportion of solar energy than does the atmosphere of the Earth, in which case the atmospheric velocity is actually less by eighty-three and four-tenths miles per hour than the equatorial tangential velocity.

There is upon *Jupiter* a delicate difference between the rates of motion in these spots; the dark spots move slightly faster than the white spots of the same belt.

This variation has also its analogue in terrestrial phenomena, for the cloudy low areas, which extend well up into the regions of high velocities, move several miles faster per hour over sea and land than do the clear high areas, which lie more in the slow moving, lower regions of the atmosphere.*

In the equatorial regions of *Jupiter*, direct solar energy causes the atmosphere to revolve faster than the planet itself, and hence the spots of this belt pass the comparatively fixed, yet floating, Red Spot. This spot, however, obeys the accelerated force of the summer winds of the southern hemisphere, which increase in force for one-half of the Jovian year, or five and ninety-three hundredths years; during the other half these winds decrease in

* See Weather Bureau U. S. Department Agriculture, monthly Charts I and IV, and corresponding tables.

force, and the acceleration is in part lost. The center of this belt of strongest winds shifts over a zone seven degrees eleven minutes wide, the inclination of the plane of the equator to the plane of the ecliptic being one-half of this arc.

In temperate latitudes the oblique rays are not capable of producing so great an acceleration, and hence the spots of these latitudes have longer periods of revolution. The northerly and southerly components of the Earth's wind systems are also greater than on *Jupiter*. This condition is brought about by the decreased heat received by the latter planet, and his shorter period of axial revolution.

The motions of the atmosphere of *Jupiter* are, therefore, simpler than those upon the Earth. This is due to the fact that upon *Jupiter* solar energy acts upon a more homogeneous surface than is offered by the partly clouded and partly clear atmosphere of the Earth, and by its varying heat-appropriating surfaces of land and water.

TELEGRAPHIC ANNOUNCEMENTS OF ASTRONOMICAL DISCOVERIES, ETC., IN AMERICA.

By Edward S. Holden.

In 1871, Dr. C. H. F. Peters, Director of the Hamilton College Observatory, addressed a letter to the Secretary of the Smithsonian Institution asking that the Institution should act as a central-office for communicating discoveries of planets, comets, etc., by telegraph. Steps were immediately taken by Professor Henry to arrange for such a service, and from 1873 to 1883 it was carried out under the auspices of the Institution. Great pains was taken by Professor Henry and Professor Baird to obtain the opinions of astronomers as to the best form of message, etc.*

These telegrams were decidedly useful to American science, in spite of many annoying errors which arose from the fact that the Institution had then no astronomer to serve as editor. The telegrams from discoverers received by the Institution were very often wrongly worded, and there was no control. These tele-

* See *Report of Smithsonian Institution*, 1882, page 57.